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Geomorphological History of the Basin and the Origin of Qinghai Lake, Qinghai Plateau, China

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Abstract

Qinghai Lake, situated in the northeastern part of Tibet-Qinghai Plateau at latitude 37°N and longitude 100°E, is a closed saline lake of 4,484 km^2 on area in the interior China. The main mountain in the basin is given attention to the highest one of 5,174 m in South Sule Mountains of northwestern side where there are found in the only existence of glacier and the lower limit of glacier exists to the altitude of 4,700 m. But, in the last glaciation, it was judged that the mountain glacier had reached to the altitude of 3,800 m.

In the lake basin, there are found remarkably the three lacustrine terraces that the relative height from the present lake-level are: 10~15 m of the lowest one (1,880 yr. B.P.), 25~50 m of the middle one (4,830 yr. B.P.) and 60~80 m of the highest one (about 8,000 yr. B.P.). The lacustrine sediment cores to the 60 m depth were obtained by the drilling near the shore of Erhai Lake in the estuary of Daotang River inflowed from the eastern basin. The sediments are given with the ^{14}C age of 7,300 yr. B.P. for 10 m depth and 30,700 yr. B.P. for 30 m depth.

The contents of water soluble salt in unit grain surface kept the lowest values during last glaciation, but it suddenly increased in the upper strata from 10 m depth, during the Holocene, reflected the condensation process resulted from the lowering of lake-level.

The Qinghai Lake had been continued probably on the situation of an open lake to the end of the Riss-Würm interglacial epoch. The ancient Daotang River had been finally closed by strong uplifting and became a closed lake in the early stage of the last glaciation. And the lake kept the lowest lake-level through the last glaciation, because the Asian monsoon became extremely weak activity. The lake-level was risen up to about 100 m in relative height by the supplying a melted water from the glacier in the opening of Holocene. After this time, the lake-level have been continued fundamentally to fall down to present.

1. Introduction

The China-Japan Joint Expedition of Qinghai Lake had been carried out in 1987, 1988, by the leadership of Prof. Kinshiro Nakao, Hokkaido University, Japan and Prof. Shi Yafeng, Lanzhou Institute of Glaciology and Cryopedology, China, to clarify the changes of the Asian monsoonal activity by the paleohydrological evaluation on the water budget of paleolake-levels and the water soluble salt record in the deep core sediments, since the late Pleistocene.

Qinghai Lake, situated in the far eastern part of Qinghai Plateau at latitude 37°N and longitude 100°E, is a closed saline lake in the interior China. Its morphometric features are: 4,484 km^2 in area estimated from a satellite photo, 27 m in maximum depth measured in July 1988 and 14.8 m in mean depth with regard to the decline of a lake-level, as based on a bathymetric map published in 1976, the lake surface being 3,193 m above mean sea level at present and the basin around the lake has an area of 25,544 km^2, estimated from a satellite photo. The first footmark to this lake was made by Kozloff's expedition supported by the Imperial Russian Geographical Society in 1908. The lake is shallowing year by year, after that the maximum depth of 36.6 m was measured by Kozloff's expedition in 1908 (Kozloff, 1909). After that, the China synthetic expedition for the Qinghai Lake was carried out by Lanzhou Institute of Geology et al. in 1962, and measured the maximum depth of 32.5 m in this time, also, it was pointed out that the Daotang River reversely had discharged to the Yellow River at the anciant time (Lanzhou Institute of Geology, 1979). Next, Sino-Swiss limnogeological expedition was made by the cooperative members headed Dr. K. Kelts in 1985 and it was concluded that the lake kept the lowest level of 5.0 m on the maximum depth through the last glaciation, based on the bottom coring near the center of lake (Kelts et al., 1988; Lister et al., 1991).

The basin is covered by a grass, being characterized by a semi arid condition. The annual precipitation and the mean annual air temperature are respectively 375 mm and -0.6°C at Gangcha, based on the record during 1959-1986 period. The seasonal variations on the precipitation are characterized by an increase in the May~October period when accounts for 90% of the annual precipitation and the snowfall amount to only 3% of the annual one. The

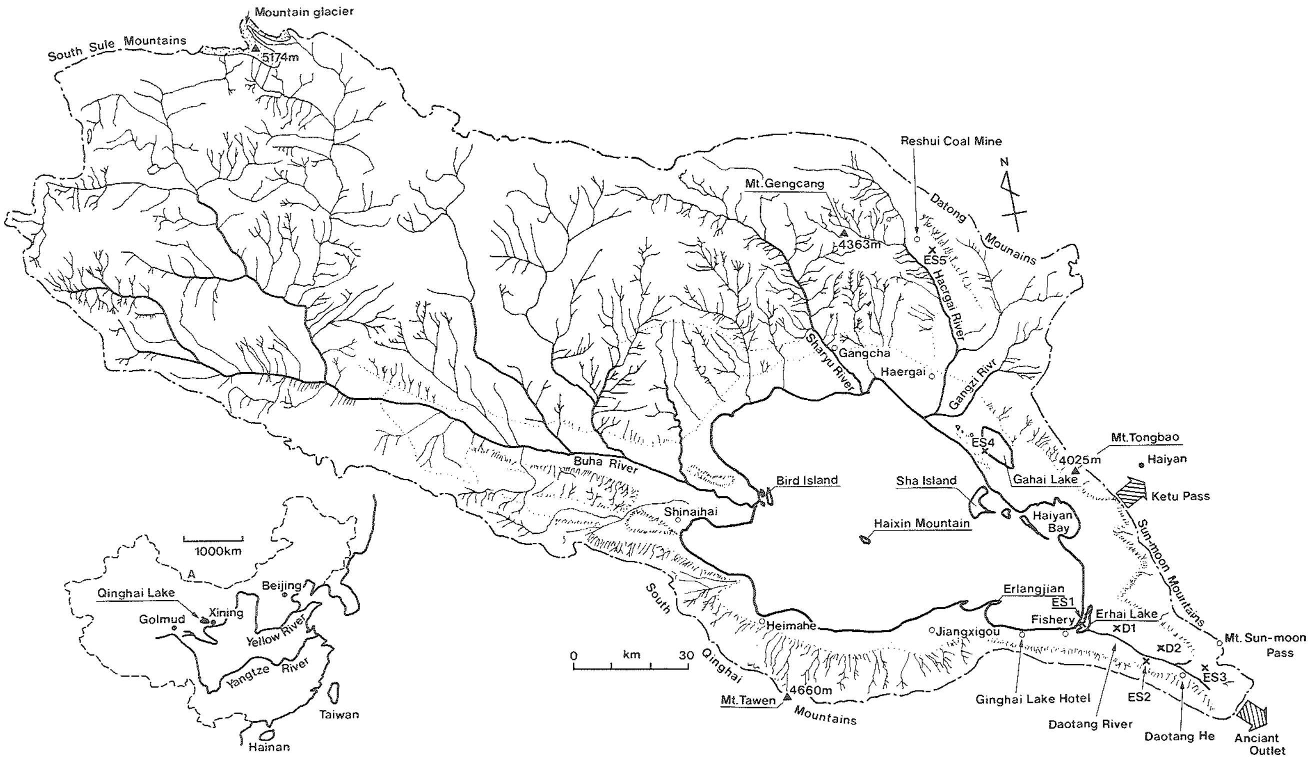


Fig. 1. Topographic outline of the Qinghai Lake Basin, was made on the basis of the satellite photo.

annual amount of evaporation calculated was 804 mm, from the meteorological date at Gangcha, based on the record for the 1958～1986 period (Nakao et al., 1995).

The topographic outline of the basin is shown in Fig. 1, based on a satellite photo. The main mountains in this basin are given attention to the following high mountains; Mt. Gengcang of 4,363 m in Daotang Mountains of northern side, Mt. Tongbao of 4,025 m in Sun-Moon Mountains of eastern side, Mt. Tawen of 4,660 m in South Qinghai Mountains of southern side and the highest mountain of 5,174 m in South Sule Mountains of nouthwestern side which there are found in the only existence of a glacier. The permafrost is discontinuously in existence over 3,400 m on the altitude.

As for the origin of this lake, the previous study (Lanzhou Institute of Geology, 1979) has led to an inference, considering the Pleistocene morphological history of the Qinghai Basin undergoing the tectonic movements, that this lake was formed by the damming a tributary of Yellow River during the period from middle Pleistocene to late Pleistocene.

2. The orign of Qinghai Lake

In the Qinghai Lake Basin, the strikes of a fault line orientate mainly to the southeastern direction and the mountain chains range to the same orientation also. Main inlet river to the lake; Buha River is characterized by a fault-line valley that it is a straight valley flowing to southeasterly.

From the lake basin to Yellow River, the discharged river was the Daotang River at ancient time. And the Daotang Valley is wide and has the deep

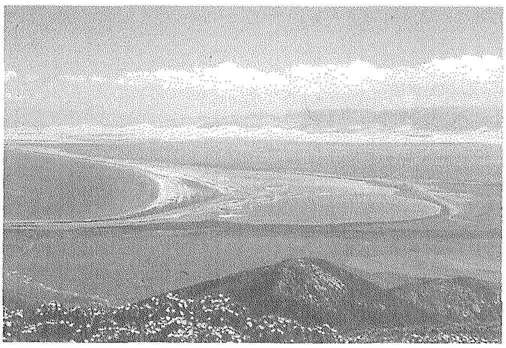


Photo 1. The crane shot points out the topographical features at the easterly shore of Qinghai Lake, Erhai Lake and near the mouth of Daotang River.

sediments, although the river is a small stream flowing into the lake at present as shown by Photo 1. Electrical depth soundings were carried out along Daotang River in August 1988 in an effort to clarify the sedimentary structure.

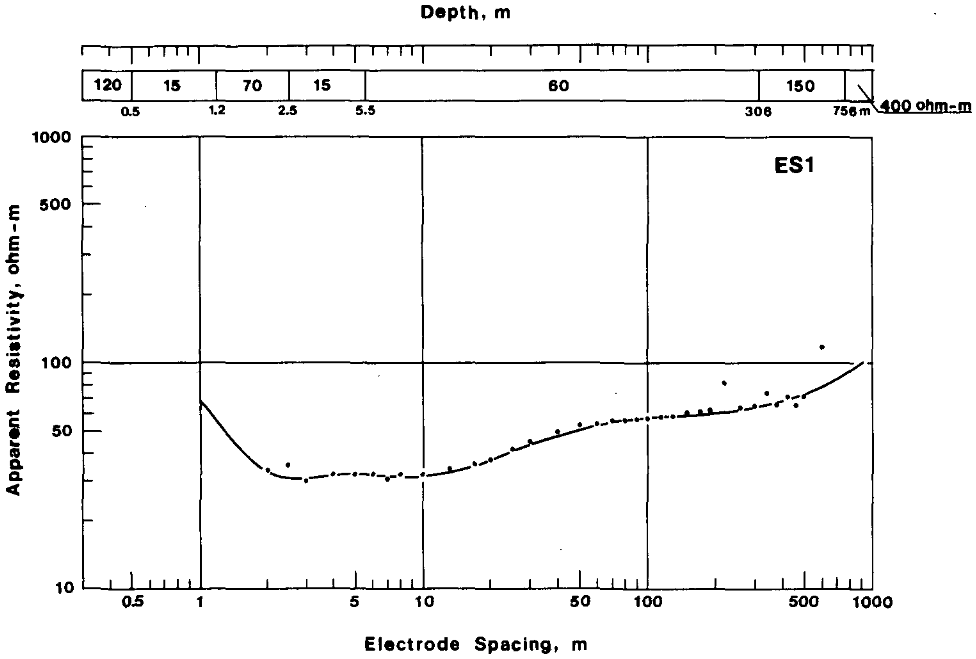
Ground resistivity was measured with a DC-type geohmmeter, whose source of power is usually provided by ten 45 volt dry batteries, thus allowing voltage regulations to 450 V. Minimum readings in measurements are 0.05 mV in voltage and 0.1 mA in current. Electrodes were arranged in the Schlumberger configuration; steel stakes were used as current electrodes; potential electrodes were copper poles inserted into cloth tubes filled with a saturated solution of copper sulfate.

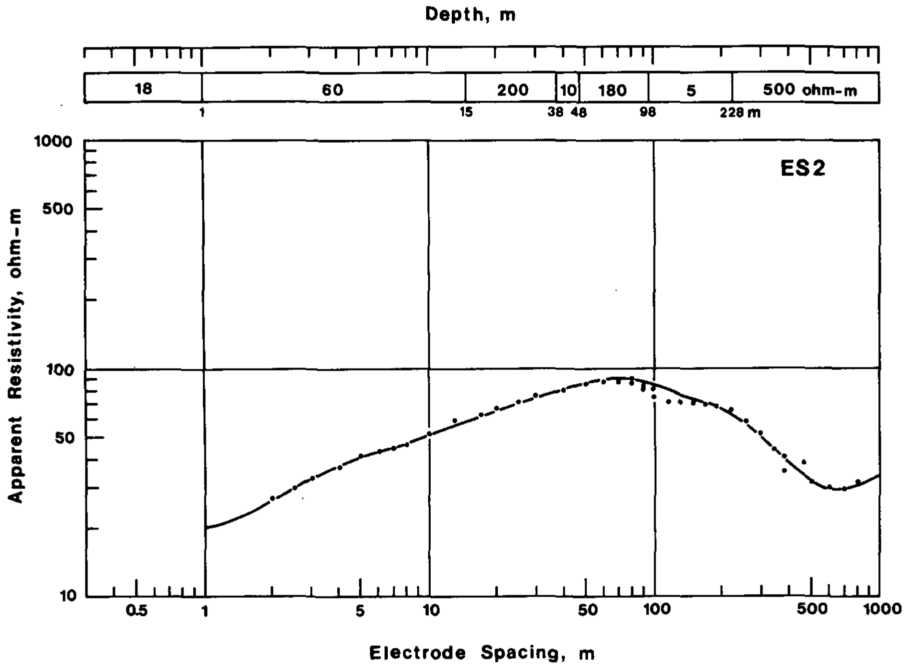
The current electrodes were extended from the center to a distance of 800 meters in the maximum span of soundings, while the spans of potential electrodes chosen were 0.5, 3, 20, 50 and 100 meters from the center, which increased with increasing distance between the current electrode and the center. Three locations were selected for electrical depth soundings along Daotang River; namely, site ES 1 near Erhai Lake, sites ES 2 and ES 3 at the downstream and the upstream of the Daotang Village, as shown in Fig. 1.

Field data were analyzed by matching the field curves to the suitable theoretical curves for multiple strata using a computer technique, as shown in Fig. 2. It followed from the interpretation of resistivity on the data measured directly for superficial sediments at each souding site and the geologic logs of drilling D 1 and D 2, that a lacustrine sediments, a secondary deposits of aeolian sediments and an ancient fluvial deposits have the resistivities of about 100~200 Ωm, 10 Ωm and 400~500 Ωm respectively, as shown in Fig. 3.

On the Daotang Valley, the sediment thickness is deeper than 400 m to a basement, and it is sufficient to understand that the valley is a graben valley which the fault-line corresponds with the same orientation for the way of the deepest zone into the lake from Buha River. And it came to the conclusion that the fluvial bed of about 300 m depth was sedimented by the ancient river when it flowed out from the basin into the Yellow River. But the bed ascends up to the direction of the Mt. Sun-Moon Pass, being approximately parallel to a ground surface. The reverse dip is judged to be a result of the uplift by a crustal movement near the Mt. Sun-Moon Pass.

Also, the aeolian sediments of 100~200 m thickness over the ancient fluvial bed maybe were deposited sencondarily by a solifluction through the last glaciation. In the last glaciation, Qinghai Lake kept the lowest level as pointed out by Lister et al. (1991). The lake was closed condition and the aeolian sediments were deposited by a solifluction on permafrost into the Daotang


Depth, m
120
15
70
15
60
150
0.5
1.2
2.5
5.5
306
756 m
400 ohm-m
ES1
Apparent Resistivity, ohm-m
1000
500
100
50
10
0.5
1
5
10
50
100
500
1000
Electrode Spacing, m


Depth, m
18
60
200
10
180
5
500 ohm-m
1
15
38
48
98
228 m
ES2
Apparent Resistivity, ohm-m
1000
500
100
50
10
0.5
1
5
10
50
100
500
1000
Electrode Spacing, m

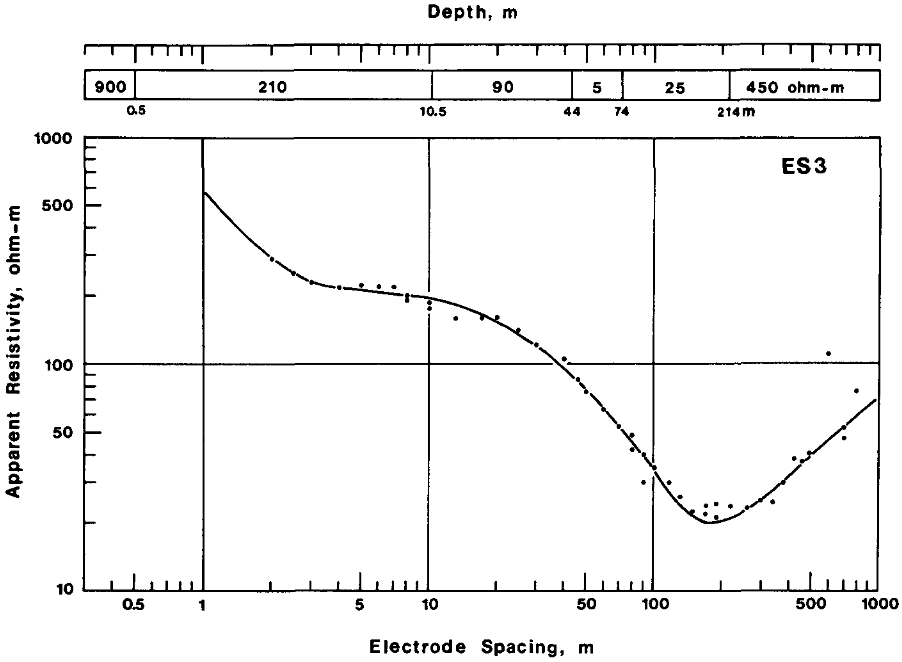


Fig. 2. Apparent resistivity curves measured by Schlumberger configuration at three sites, ES 1, ES 2 and ES 3 along Daotang River in August 1988. Evaluated resistivity-depth column is shown in the upper part of the figure.

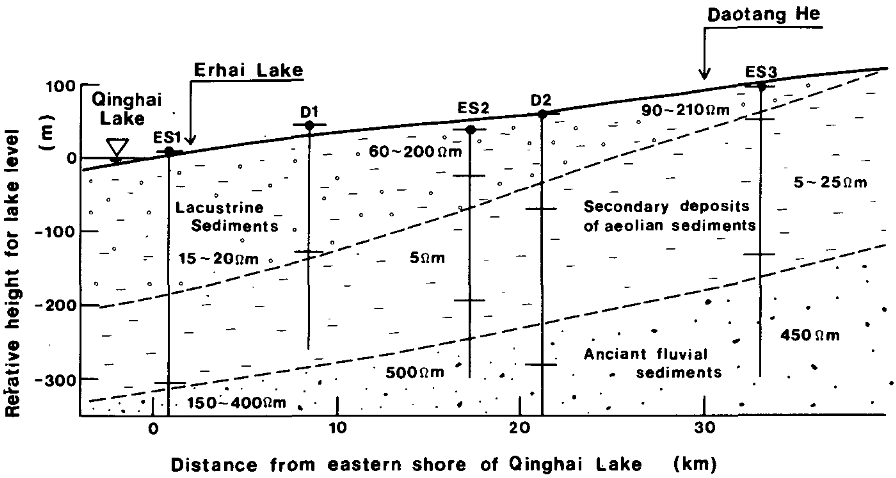


Fig. 3. Sedimentary structure along Daotang River is composed by the strata of lacustrine sediments, secondary deposits of aeolian sediments and ancient fluvial sediments from ground surface.

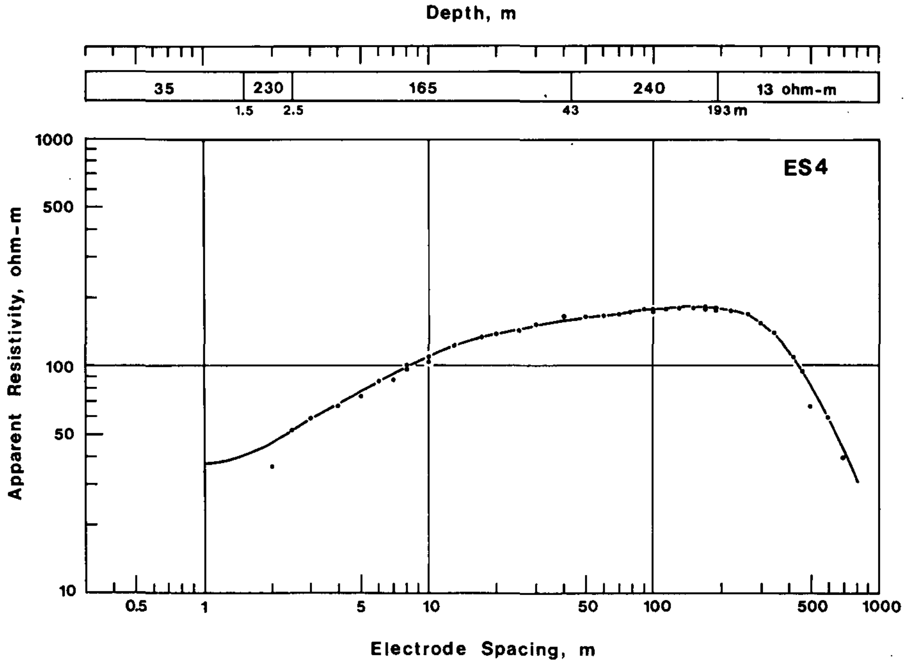


Fig. 4. Apparent resistivity curve measured by Schlumberger configuration at the site of ES 4, the southern shore of the Gahai Lake in August 1988. Evaluated resistivity-depth column is shown in the upper part of the figure.

Valley during the last glaciation.

The lacustrine sediments expand to the extent of relative height of about 100 m. Also, we found out the several relic lagoons at the upstream of present lagoon ; Erhai Lake in the Daotang Valley. It was shown clearly that the lake-level was risen up to about 100 m by the supplying of a melted water from a mountain glacier, in the opening of Holocene.

Other location was selected as site ES 4 for electrical depth sounding on the southern shore of Gahai Lake at the northeastern side of the Qinghai Lake as shown in Fig. 1. The sediment is very thick and the basement is in far excess of 200 m in depth as shown in Fig. 4. From the results of the sounding, it was judged with reference to the geomorphic map published by Institute of Geography in 1985 that the lake basin was originally formed as a fault basin. Futhermore, it was inferred from the examination on the condensation processes of a lake water, that this lake was finally closed by damming of ancient Daotang River in the early time of the last glaciation ; namely, Würm Glacial Stage.

3. Geomorphological evidences during the last glaciation

To examine the lower limit and activity of a mountain glacier during the last glaciation, study areas were selected near the mountain peak in the distances of 10 km from the Yuchang Fishery to the south direction, in South Qinghai Mountains, as given consideration to the topographic map on a scale of 1 to 50,000.

The mountain slopes above 4,100 meters in an altitude are almost covered by a creeping rock. The lower limit of a cirque floor showed an altitude of 4,050 meters during the last glaciation, as shown in Fig. 5 and the floor has been mostly buried by a rock glacier from mountain slope of both sides, as shown in Photo 2. On the other hand, an U shaped valley and a glacial landform could be tracked out to about 3,800 meters in the lower limit of an altitude by our geomorphological surveying. Then, it was judged that the mountain glacier had reached to the altitude of 3,800 meters by the overflowing from a cirque as shown by the valley shapes in A and B sections of Fig. 5, in the end of the last glaciation when the ice storage had reached a maximum in a mountainous region. On this plateau, it is found that the lower limit of modern glacier exists in an altitude of 4,700 meters. The fall of height is shown as the 900 meters in the miximum of the last glaciation. Then, it was simply estimated that the values of an air temperature rose up about 4.5°C in annual mean, after the last glaciation, for a lapse-rate of air temperature given as 0.5°C/100 m.

In the basin of Qinghai Lake, a permafrost is discontinuously found above the height of 3,400 meters. The location for electrical depth sounding on a

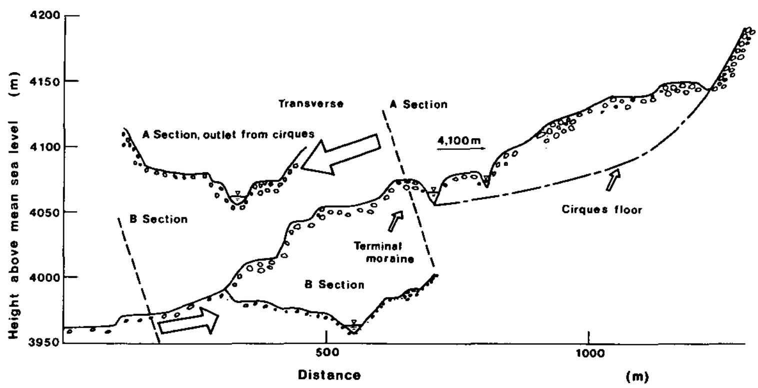


Fig. 5. Geomorphological feature of the cirque is shown by the surveying in August 1988, in South Qinghai Mountains.

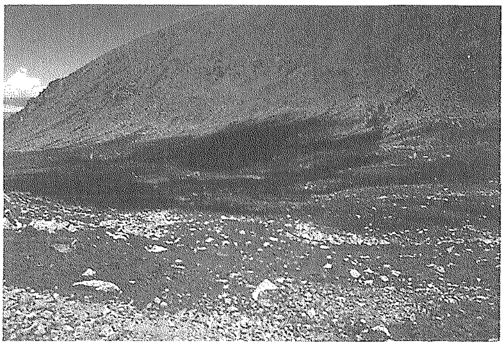


Photo 2. Cirque floor has been mostly buried by a rock glacier from mountain slope.

permafrost ground, was selected in piedmont alluvial plain of Datong Mountains; named site ES 5 as shown in Fig. 1. The site is located on the height of 3,550 meters, about 5 km to the southwest of the Reshui Coal Mine. The annual mean of an air temperature is recorded with the values of $-2.5°C$ at Reshui Coal Mine, on the height of 3,600 meters. In here, it is known by the personal communication of Chinese side that the permafrost depth reaches to the depths ranging from 8 m to 30 m respectively, corresponding with the sites of 3,486 and 3,696 meters on a height.

The value of Z_p is calculated basically by the following equation:

$$Z_p = -(K/q)\ T_a,$$

where Z_p : permafrost depth, namely, from 8 m to 30 m;
K : thermal conductivity of permafrost;
q : terrestrial heat flow, namely, 1.5×10^{-6} cal/cm^{2}s
T_a : mean annual air temperature, namely, $-2.5°C$ at Reshui Coal Mine.

The values of K were calculated the conductivities ranging from 0.78×10^{-3} to 1.8×10^{-3} cal/cms°C for Z_p given as 8 to 30 m. The values of K are generally given as 2×10^{-3} or 3×10^{-3} cal/cms°C, for a soil. Electrical depth sounding at site ES 5 indicated the noticeable evidence that the layer having the high resistivity of 1,500 Ωm laid between from 71 to 116 m depth, as shown in Fig. 6. It is concluded from the previous studies (Nakao et al., 1986a, b) that the depth of 116 m is the base of a permafrost in the last glaciation.

Mean annual air temperature is estimated as $-7.0°C$ at the site in the last glaciation, for the rise of T_a given as 4.5°C, based on the altitude change of the lower limit of a mountain glacier after glaciation. Through the last glaciation, the value of K was estimated as 2.5×10^{-3} cal/cms°C for Z_p and T_a given as 116

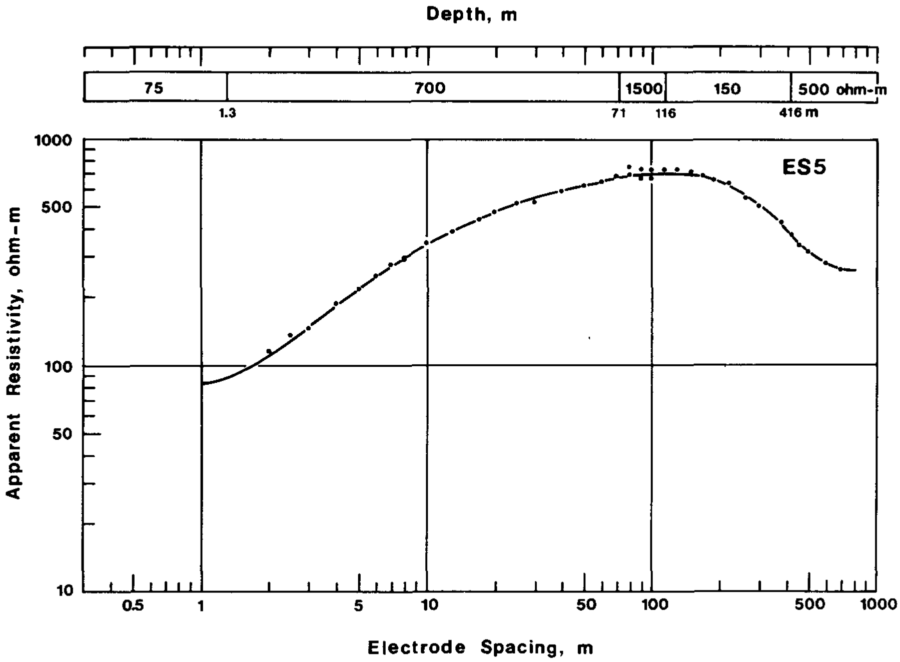


Fig. 6. Apparent resistivity curve measured by Schlumberger configuration at the site of ES 5, near the Reshui Coal Mine in August 1988. Evaluated resistivity-depth column is shown in the upper part of the figure.

m and −7.0°C, respectively. This value ($K=2.5\times10^{-3}$ cal/cms°C) was judged to be a proper value, becoming little high because it was lower than present one on the ground temperature during the last glaciation, in the consideration of the values of $K=7\times10^{-3}$ cal/cms°C at Barrow, Alaska (Gold and Lachenbruch, 1973). The relic permafrost depth agrees nearly with the depth evaluated from the mean annual air temperature during the last glaciation. Therefore, it was concluded clearly, based on the existence of a relic permafrost in deep depth that there were ice free to the altitude of 3,600 meters during the last glaciation.

4. Fluctuation of lake levels from the last glaciation to present

In the basin of Qinghai Lake, there are found the lacustrine terraces on the many heights, carrying out the measurements of a geomorphic profile by an electoronic theodolite of Theomat Wild T-2,000. The land profile along Janshigu River was paid a special attention as the typical example in this basin as

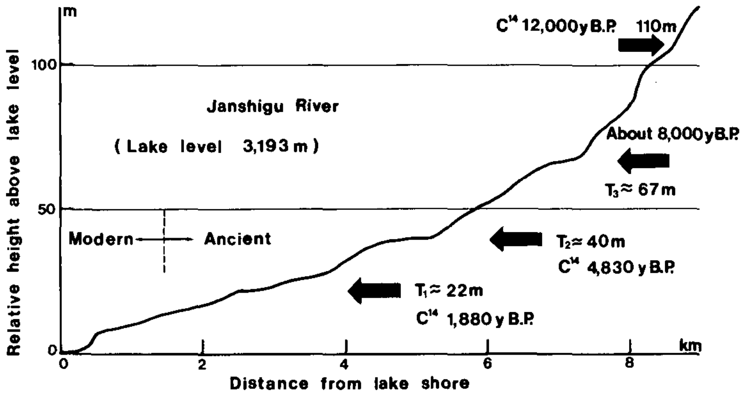


Fig. 7. The land profile along the Janshigu River shows typically the three lacustrine terraces of T_1, T_2 and T_3.

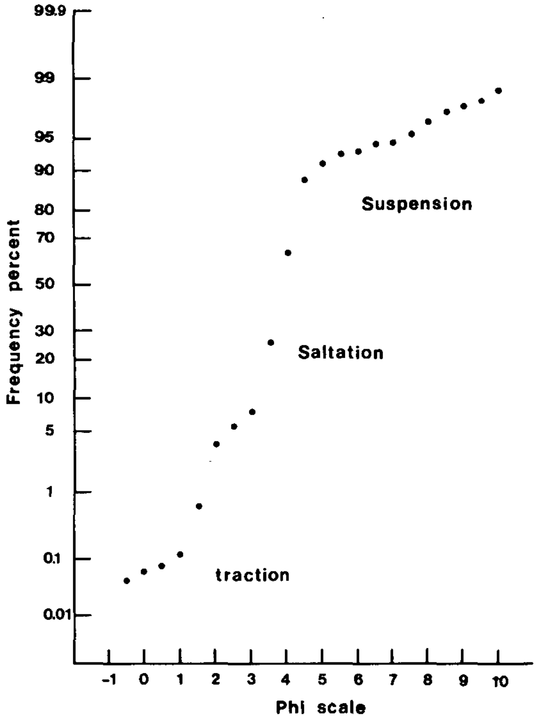


Fig. 8. The size frequency distribution of the sand covered over a rock bench at the foot of a mountain is characterized by an aeolian sediments.

shown in Fig. 7. The remarkable terraces are made on the plain being a gentle slope ; namely, T_1 of the lowest one on relative height of 22 meters from present lake-level, 40 meters for T_2 of middle one and 67 meters for T_3 of the highest one.

The sedimentation ages of T_1 and T_2 were measured by ^{14}C dating of a fossil shell in the sediments, and the values showed $1,880 \pm 90$ yr. B.P. for T_1 and $4,830 \pm 130$ yr. B.P. for T_2. Also, the highest terrace of T_3 judged about 8,000 yr. B.P. for the sedimented age, based on the results of a chemical analysis and ^{14}C datings for a sediment core at the Daotang drilling site.

Our geomorphic surveyings found the rock bench covered by a sand, on the relative height of 110 meters at the upstream of Janshigu River. The bench locates at the foot of a mountain in contact with an alluvial plain of gentle mountain slope, namely, as a piedmont. The small pieces of wood contained in the sand showed ^{14}C age of $12,000 \pm 100$ yr. B.P., and the size frequency distribution of the overbeding sand was characterized by an aeolian sediments resulted from three depositional processes ; suspension (fine grains) ; saltation (medium grains) ; traction (coarse grains), as shown in Fig. 8.

It might be concluded that the rock bench had been formed by the erosion of a melting water of a glacier ice in the climatic warming, after then the lake level rapidly rose up to the relative height of nearly 110 meters, and at this time the aeolian sand might be deposited over the rock bench by the supply from the highest shore.

5. Conclusions

The Qinghai Lake had been continued with the situation of an open lake to the end of the Riss-Würm interglacial epoch. After then, Daotang River was finally closed by the uplifting near the Mt. Sun-Moon Pass and the lowest lake level kept through the last glaciation because the Asian monsoon became extremely weak activity.

Through the Würm glaciation, the greater part of precipitation were stored in the form of an ice covered the mountainous region and the discharge from the drainage basin to lake decreased extremely. In this time, it is estimated as $-5.1^{\circ}C$ near the lake for the mean annual air temperature. And also, the mountain glacier had reached to the altitude of 3,800 meters in the miximum of the glaciation. The lake basin was perhaps characterized by a tundra and a permafrost in a swampy land and the lowland had been deposited secondarily by the solifraction of an aeolian sediments from a piedmont.

In the opening of Holocene, about 12,000 yr. B.P., the lake level was risen up to about 110 meters in relative height by the supplying of a melted water from mountain glacier. After that, the lake levels have fundamentaly continued to fall down to present.

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